DECLARATION

I, Yukie NAKATSU, residing at 1-47-2-524 Sasazuka, Shibuya-ku, Tokyo, Japan, do hereby certify that I am conversant with the English and Japanese languages and am a competent translator thereof. I further certify that to the best of my knowledge and belief the attached English translation is a true and correct translation made by me of U.S. Provisional Patent Application No. 60/432,247 filed on December 11, 2002.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 30th day of March, 2004

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[Document Name] Specification

[Title of the Invention] Composite Material for Polishing, Grinding Stone, Grinding Material, Polishing Material and Processing Method for Electronic Parts and Silicon

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Pertains]

The present invention relates to a composite material containing abrasive grains employed for grinding or polishing, such as a wheel or a blade. More particularly, the present invention relates to an abrasive composite material employed for precision grinding or precision polishing of an electronic part such as a semiconductor wafer, an interlayer insulating film, or a wiring material by means of the fixed abrasive method; to a grinding material or polishing material containing the composite material; and to a method for processing an electronic part such as a semiconductor wafer, the method employing the composite material.

[0002]

[Background Art]

In recent years, keeping pace with the advancement in high-performance semiconductor devices, electronic circuits have attained increased degree of integration and miniaturization. Successful formation of a sophisticated wiring structure on the surface of a semiconductor substrate

calls for planarization of the imaging surface; i.e., the semiconductor substrate surface. This process is critical for alleviating the miniaturization limit of circuit patterns formed by photolithography, or stated differently, the shallow focal depth.

In a generally employed method for attaining semiconductor substrate planarization by means of chemical mechanical polishing, a substrate supported by a carrier is rotated while a slurry prepared by dispersing abrasive grains in an abrasive liquid is supplied to a polishing pad, whereby the substrate is polished. For example, a slurry for polishing an insulating film is prepared by dispersing, in an abrasive liquid, silicon dioxide (see, for example, Patent Document 1), cerium oxide (see, for example, Patent Document 2), or a similar substance. Such a method, which employs a relatively soft polishing pad in order to prevent damage to a substrate, involves a problem in terms of low polishing speed attributed to the abrasive grains not being held on the polishing pad. In the case where a circuit-pattern-printed substrate is polished, the polishing speed varies in accordance with the distance between circuit wiring patterns, leading to occurrence of non-uniform polishing, such as dishing or thinning. In addition, such a method involves a problem in terms of, for example, treatment of used abrasive grains.

[0003]

In order to solve problems associated with the

aforementioned semiconductor substrate planarization method, there has been proposed another method in which a substrate is pressed onto a rotating disk onto which abrasive grains are fixed, and the substrate is polished while the disk is rotated or slid (see, for example, Patent Document 3, 4, or 5).

This method is advantageous in that a relatively high polishing speed is achieved, by virtue of the fixed abrasive grains.

[0004]

[Patent Document 1]

Japanese Patent Application Laid-Open (*kokai*) No. 2001-26771

[Patent Document 2]

Japanese Patent Application Laid-Open (*kokai*) No. 2001-179610

[Patent Document 3]

Japanese Patent Application Laid-Open (*kokai*) No. 10-329031

[Patent Document 4]

Japanese Patent Application Laid-Open (*kokai*) No. 11-333705

[Patent Document 5]

Japanese Patent Application Laid-Open (*kokai*) No. 2001-49243

[0005]

[Problems to be Solved by the Invention]

However, such a polishing method employing fixed abrasive grains involves problems, including generation of micro-scratches during the course of polishing, and generation of deep polishing marks attributed to falling of abrasive grains. Such scratches cause short circuit, thereby tending to lower the yield of the resultant device.

In order to attain production of a high-performance semiconductor device, precision of polishing of the surface of a substrate must be improved, and a substrate having neither scratches nor polishing marks must be provided.

In addition, there is required means for polishing a substrate without forming scratches thereon and for precisely polishing elements constituting the device, such as an interlayer insulating film and a circuit pattern.

[0006]

In view of the foregoing, the present invention has been completed. The present invention contemplates a grinding material, a polishing material, a grinding method, and a polishing method, the material or the method enabling production of a substrate having surfaces with neither scratches nor polishing marks, by performing improved precision polishing of surfaces of, for example, substrates, interlayer insulating films, or circuit patterns.

Specifically, the present invention contemplates a grinding material, a polishing material, a grinding method, and a polishing method, the material or the method enabling suppressing falling of abrasive grains during the course of

grinding or polishing, suppressing generation of polishing marks, reducing burden on post-treatment of abrasive grains, and providing the grinding material or polishing material with long lifetime.

The present invention also contemplates an abrasive composite material which can be formed into a grinding material or a polishing material exhibiting improved tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance, and which leads to an improved precision in grinding or polishing of a workpiece, to thereby reduce adverse effects caused by physical or chemical factors during the course of processing.

[0007]

The present invention further contemplates a method for processing an electronic part, the method including grinding or polishing an interlayer insulating film or a circuit pattern constituting a semiconductor substrate or a electronic device, by use of a grinding material or a polishing material comprising such a high-performance abrasive composite material.

In particular, the present invention contemplates a method for processing silicon, the method including grinding or polishing silicon such as polycrystalline silicon, single-crystal silicon, and amorphous silicon.

[0008]

[Means for Solving the Problems]

In order to solve the aforementioned problems, the present inventors have performed studies, and as a result have invented an abrasive composite material, a grinding wheel comprising the composite material, a grinding material comprising the composite material, and a polishing material comprising the composite material, as described below. In addition, the present inventors have invented a method for processing an electronic part, and a method for processing silicon, the methods employing the grinding wheel, grinding material, or polishing material.

The abrasive composite material of the present invention contains carbon fiber and therefore exhibits excellent tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance. Therefore, when the abrasive composite material is employed, falling of abrasive grains is suppressed, friction resistance is reduced, non-uniform polishing is prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be attained.

No particular limitations are imposed on the abrasive grains or matrix employed in the abrasive composite material of the present invention, and the abrasive grains or matrix can be formed of a conventionally known material.

The grinding wheel, the grinding material, or the polishing material of the present invention contains carbon fiber and therefore exhibits excellent tribological characteristics, elasticity, electrical conductivity, thermal

conductivity, and corrosion resistance. Therefore, when the abrasive composite material is employed, falling of abrasive grains is suppressed, friction resistance is reduced, non-uniform polishing is prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be attained.

When the processing method of the present invention is employed for grinding or polishing of silicon or a variety of electronic parts, falling of abrasive grains is suppressed, friction resistance is reduced, non-uniform polishing is prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be attained.

[0009]

Accordingly, the present invention provides the following.

(1) An abrasive composite material, characterized by comprising a matrix, abrasive grains, and carbon fiber having a multi-layer structure, each fiber filament of the carbon fiber having an outer diameter of 2 to 500 nm and an aspect ratio of 5 to 15,000, and including a hollow space extending along its center axis.

(2) An abrasive composite material according to (1), wherein the carbon fiber has a BET specific surface area of at least 4 m^2/g.

(3) An abrasive composite material according to (1) or (2), wherein the carbon fiber has, at a carbon (002) plane, an interlayer distance (d_{002}) of 0.345 nm or less as measured

by means of X-ray diffractometry.

(4) An abrasive composite material according to any one of (1) through (3), wherein the ratio of the peak height (Id) of the band at 1,341 to 1,349 cm^{-1} in a Raman scattering spectrum of the carbon fiber to the peak height (Ig) of the band at 1,570 to 1,578 cm^{-1} in the spectrum; i.e., Id/Ig, is 1.5 or less.

(5) An abrasive composite material according to any one of (1) through (4), wherein the carbon fiber contains branched vapor grown carbon fiber.

(6) An abrasive composite material according to any one of (1) through (5), wherein boron is contained, in an amount of 0.01 to 5 mass%, in the interior of crystals constituting the carbon fiber.

(7) An abrasive composite material according to any one of (1) through (6), wherein the amount of the carbon fiber is 5 to 40 vol.% with respect to the abrasive composite material.

[0010]

(8) An abrasive composite material according to (1), wherein the abrasive grains are formed of at least one material selected from among cerium oxide, silicon oxide, silicon carbide, boron carbide, boron nitride, zirconium oxide, diamond, and sapphire.

(9) An abrasive composite material according to (1), wherein the matrix is formed of at least one material selected from among a resin, a metal, and a ceramic material.

(10) An abrasive composite material according to (9),

wherein the resin forming the matrix contains at least one species selected from among a phenolic resin, a melamine resin, a polyurethane resin, an epoxy resin, a urea resin, an unsaturated polyester resin, a silicone resin, a polyimide resin, an epoxy resin, a cyanate ester resin, and a benzoxazine resin.

(11) A grinding wheel characterized by being formed through molding of an abrasive composite material as recited in any one of (1) through (10).

[0011]

(12) A grinding material or a polishing material, characterized by comprising an abrasive composite material as recited in any one of (1) through (10).

(13) A method for processing an electronic part, characterized by grinding or polishing a semiconductor, an interlayer insulating film, or a wiring material by use of a grinding wheel as recited in (11) or a grinding material or a polishing material as recited in (12).

(14) A method for processing silicon, characterized by grinding or polishing polycrystalline silicon, single-crystal silicon, and amorphous silicon by use of a grinding wheel as recited in (11) or a grinding material or a polishing material as recited in (12).

[0012]

[Modes for Carrying Out the Invention]

The present invention will next be described in detail.

The abrasive composite material of the present

invention contains a matrix (e.g., substrate or fabric), abrasive grains, and carbon fiber, wherein the abrasive grains and carbon powder are fixed onto the matrix. The abrasive composite material can be formed into, for example, a grinding wheel through molding of a mixture of the matrix, which also serves as a binder, the abrasive grains, and the carbon fiber; a polishing blade by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of a metallic or ceramic substrate serving as the matrix; or a polishing pad by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of the matrix formed of non-woven fabric.

As used herein, the term "grinding" refers to a process for removing a member, the process including cutting; and the term "polishing" refers to a process for reducing irregularities on the surface of a member, thereby smoothing the member surface. As used herein, the terms "grinding material" and "polishing material" refer to materials employed for the aforementioned respective processes. Specific examples of products produced from the grinding material or the polishing material include a grinding wheel, a polishing wheel, a grinding blade, a polishing pad, and a dresser.

[0013]

(Abrasive grains)

No particular limitations are imposed on the type of abrasive grains employed in the present invention, and, in

accordance with the type of a target workpiece, the abrasive grains may be selected from among conventionally known substances, for example, cerium oxide, silicon oxide, aluminum oxide, titanium oxide, zirconium oxide, silicon carbide, tungsten carbide, boron carbide, boron nitride, diamond, sapphire, and organic fine particles. When the abrasive composite material is employed in the semiconductor field, the abrasive grains are particularly preferably formed of at least one species selected from among cerium oxide, silicon oxide, and aluminum oxide.

The size of the abrasive grains employed in the present invention varies within a range of 0.1 to 100 μm, in accordance with the degree of surface finishing of a workpiece. Preferably, the abrasive grains have a size of 0.3 to 50 μm. When the grain size is 0.1 μm or less, protrusions of the abrasive grains becomes small, and the polishing speed is considerably reduced, whereas when the grain size is 100 μm or more, the polishing speed increases, but the number of polishing marks on the surface of the resultant workpiece increases, the depth of the marks increases, and the surface roughness of the workpiece increases.

[0014]

When the abrasive composite material is formed into a grinding wheel, the amount of the abrasive grains added to the composite material is preferably 3 to 30 vol.%, more preferably 5 to 20 vol.%. When the amount of the abrasive

grains is 3 vol.% or less, the polishing speed decreases, sufficient planarization fails to be attained within a short period of time, whereas when the amount of the abrasive grains is 30 vol.% or more, adhesion of a resin to the abrasive grains is lowered, and falling of the abrasive grains considerably occurs, resulting in an increase in the number of polishing marks.

When the abrasive grains are fixed onto the surface of the matrix, preferably, the ratio by volume of the abrasive grains to the carbon fiber is regulated to 1:0.5 to 1:1.

[0015]

(Matrix)

Examples of the matrix employed in the present invention include resins such as plastic and rubber; ceramic materials such as cement and glass; and metals such as pure metals and alloys. Such a matrix may serve as a bond. The means for fixing the abrasive grains or carbon fiber onto the matrix may be any type of bond, such as resinoid bond, metal bond, vitrified bond, and electroplated bond.

[0016]

No particular limitations are imposed on the resin employed in the present invention, and a known resin may be employed. Examples of the resin which may be employed include thermosetting resins such as polyamide, polyether, polyester, polyimide, polysulfone, epoxy resin, unsaturated polyester, and phenolic resin; and thermoplastic resins such as nylon, polyethylene, polycarbonate, and polyarylate. Such

a resin may be employed in combination with a foaming agent. If desired, there may be employed a foam regulating agent, an additive for regulating dispersion, humidity, or wettability of the abrasive grains, or a coupling agent for regulating the strength of bonding between the resin and the abrasive grains.

In the case where a resin is employed as the matrix, the resin, the abrasive grains, and the carbon fiber may be mixed together, and the resultant mixture may be subjected to compression molding, thereby forming a grinding wheel. Alternatively, the abrasive grains and the carbon fiber may be fixed, by use of a bond, onto the surface of a substrate or non-woven fabric formed of the resin serving as the matrix.

[0017]

In the case where the abrasive grains and the carbon fiber are fixed onto the surface of a metallic or ceramic matrix, metal bond can be employed. The metal bond may be an alloy of copper, tin, iron, nickel, cobalt, or a similar metal. Vitrified bond is a ceramic or glassy bond (inorganic bond) prepared through sintering at 800 to 1,000°C. Electroplated bond is means for fixing the abrasive grains through electroplating.

[0018]

(Carbon fiber)

The carbon fiber employed in the present invention is preferably vapor grown carbon fiber. In general, vapor grown carbon fiber can be produced by thermally decomposing an

organic compound by use of an organo-transition metallic compound.

Examples of the organic compound which may serve as a raw material of the vapor grown carbon fiber include toluene, benzene, naphthalene, ethylene, acetylene, ethane, gasses such as natural gas and carbon monoxide, and mixtures thereof. Of these, aromatic hydrocarbons such as toluene and benzene are preferred.

An organo-transition metallic compound contains a transition metal serving as a catalyst, and is an organic compound containing, as a transition metal, a metal belonging to Group IVa, Va, VIa, VIIa, or VIII of the periodic table. An organo-transition metallic compound such as ferrocene or nickelocene is preferred.

The vapor grown carbon fiber is produced through the following procedure: the aforementioned organic compound and organo-transition metallic compound are gasified, and mixed with a reducing gas (e.g., hydrogen) which has been preliminarily heated to 500 to 1,300°C; and the resultant mixture is fed into a reaction furnace heated to 800 to 1,300°C, to thereby allow reaction to proceed.

[0019]

In order to enhance adhesion of the vapor grown carbon fiber to the matrix, preferably, the carbon fiber is subjected to thermal treatment in an inert atmosphere at 900 to 1,300°C, to thereby remove organic substances (e.g., tar) deposited on the surface of the carbon fiber.

In order to further enhance adhesion of the vapor grown carbon fiber to the matrix, the carbon fiber may be subjected to thermal treatment in an oxidative atmosphere at 300 to 450°C, or may be activated by use of, for example, carbon dioxide gas or potassium hydroxide, to thereby increase the area of a portion of the carbon fiber that adheres to the matrix.

The surface area of the vapor grown carbon fiber can be increased by means of dry milling employing, for example, a vibration mill or a jet mill, or by means of wet milling employing, for example, a bead mill.

In order to enhance affinity of the vapor grown carbon fiber to the matrix, the carbon fiber surface or the entirety of the carbon fiber may be subjected to, for example, fluorination or oxidation.

[0020]

In order to improve characteristics (e.g., electrical conductivity and thermal conductivity) of the vapor grown carbon fiber, the carbon fiber may be subjected to thermal treatment in an inert atmosphere at 2,000 to 3,500°C, to thereby enhance crystallinity thereof. In order to further enhance crystallinity and electrical conductivity of the vapor grown carbon fiber, the carbon fiber may be mixed with a boron compound such as boron carbide (B_4C), boron oxide (B_2O_3), elemental boron, boric acid (H_3BO_3), or a borate, and the resultant mixture may be subjected to thermal treatment in an inert atmosphere at 2,000 to 3,500°C, such that boron

(B) is contained, in an amount of 0.01 to 5 mass%, in carbon crystals constituting the carbon fiber.

The vapor grown carbon fiber may be thermally treated by use of any furnace, so long as the furnace can maintain a target temperature of 2,000°C or higher, preferably 2,300°C or higher. The furnace may be a generally employed furnace, such as an Acheson furnace, a resistance furnace, or a high-frequency furnace. In some cases, there may be employed a method for heating powder or a molded product formed through compression of the vapor grown carbon fiber by applying electricity directly thereto.

Thermal treatment is carried out in a non-oxidative atmosphere, preferably in an atmosphere of one or more of rare gasses such as argon, helium, and neon. From the viewpoint of productivity, thermal treatment is preferably carried out within a short period of time. When carbon fiber is heated over a long period of time, the carbon fiber is sintered to form aggregates, resulting in low production yield. Therefore, after the center of a molded product of the carbon fiber is heated to a target temperature, the molded product is not necessarily maintained at the temperature for more than one hour.

[0021]

Each fiber filament of the vapor grown carbon fiber employed in the present invention preferably has an outer diameter of 2 to 500 nm. In order to cause the carbon fiber to sufficiently exhibit its characteristics, including

tribological characteristics and electrical conductivity, the carbon fiber must be dispersed uniformly in the abrasive composite material. The outer diameter of the carbon fiber filament is more preferably 10 to 300 nm, much more preferably 20 to 200 nm. The greater the amount of the vapor grown carbon fiber distributed over the surface of the abrasive composite material, the more enhanced the tribological characteristics. When the outer diameter is less than 5 nm, difficulty is encountered in uniformly dispersing the carbon fiber in the abrasive composite material, and friction resistance becomes non-uniform in the composite material, which causes non-uniform polishing. In contrast, when the outer diameter exceeds 500 nm, a large amount of the carbon fiber must be added to the abrasive composite material in order to impart intended electrical conductivity and thermal conductivity to the composite material. As a result, the mechanical strength of the abrasive composite material is lowered, and polishing marks attributed to falling of the abrasive grains or carbon fiber tend to be formed during the course of polishing.

[0022]

Each fiber filament of the vapor grown carbon fiber employed in the present invention preferably has an aspect ratio of 5 to 15,000. In order to facilitate uniform dispersion of the carbon fiber in the abrasive composite material, more preferably, the aspect ratio of the carbon fiber filament is regulated to 10 to 100.

When the aspect ratio is less than 5, the carbon fiber loses its characteristic feature in terms of fibrous form, and the carbon fiber fails to impart intended electrical conductivity and thermal conductivity to the abrasive composite material. In contrast, when the aspect ratio exceeds 15,000, fiber filaments of the carbon fiber are entangled with one another, and difficulty is encountered in uniformly dispersing the carbon fiber in the abrasive composite material. As a result, immediately after the composite material is molded into a grinding wheel, planarity of the surface of the grinding wheel is impaired, and friction resistance becomes non-uniform in the grinding wheel surface, which causes low planarity of a workpiece.

[0023]

The carbon fiber employed in the present invention preferably has a BET specific surface area of 4 m^2/g or more.

When the BET specific surface area is less than 4 m^2/g, the area of a portion of the carbon fiber that adheres to the matrix becomes small, and thus the carbon fiber is not sufficiently captured by the matrix, leading to falling of the carbon fiber from the abrasive composite material during the course of grinding or polishing, which causes generation of scratches or polishing marks.

[0024]

The carbon fiber employed in the present invention preferably has, at a carbon (002) plane, an interlayer distance (d_{002}) of 0.345 nm or less as measured by means of X-

ray diffractometry.

When the (d_{002}) value exceeds 0.345 nm, thermal conductivity and tribological characteristics are impaired, which reduces the ability to radiate heat generated during polishing, leading to problems, including polishing burn.

[0025]

In the carbon fiber employed in the present invention, preferably, the ratio of the peak height (Id) of the band at 1,341 to 1,349 cm^{-1} in a Raman scattering spectrum of the carbon fiber to the peak height (Ig) of the band at 1,570 to 1,578 cm^{-1} in the spectrum; i.e., Id/Ig, is 1.5 or less.

Id of the Raman spectrum is the height of the peak of a broad band corresponding to an increase in disturbance of a carbon structure, and Ig is the height of the peak of a relatively sharp band corresponding to a complete graphite structure. In general, the peak intensity ratio is employed as an indicator for the degree of graphitization of a carbon material. In the case where the peak intensity ratio is represented by the peak height ratio, when the degree of graphitization is higher, the peak height ratio becomes lower.

When the ratio Id/Ig exceeds 1.5; i.e., crystallinity of a graphene sheet is low, the carbon fiber exhibits lowered electrical conductivity and thermal conductivity. Therefore, in some cases, difficulty is encountered in imparting intended electrical conductivity and thermal conductivity to the abrasive composite material.

[0026]

The carbon fiber employed in the present invention has a multi-layer structure, each fiber filament of the carbon fiber including a hollow space extending along its center axis. Since each fiber filament of the carbon fiber includes a hollow space, the carbon fiber exhibits enhanced elasticity, and therefore the abrasive composite material exhibits enhanced polishing efficiency and enables suppression of generation of polishing marks. In addition, since the carbon fiber has a multi-layer structure, the carbon fiber exhibits high lubricity, and the abrasive composite material enables suppression of generation of polishing marks. Such a carbon fiber structure (i.e., a multi-layer structure including a central hollow space) is specific to carbon fiber produced through the vapor phase process.

The carbon fiber employed in the present invention may contain branched vapor grown carbon fiber. In many cases, branched vapor grown carbon fiber has a small outer diameter, and each fiber filament of the carbon fiber has a structure in which a central hollow portion extends throughout the filament including a branched portion thereof. In the case where branched vapor grown carbon fiber is added to the abrasive composite material, even when the amount of the carbon fiber is small, an electrically conductive or thermally conductive network can be efficiently formed in the composite material, as compared with the case where typical vapor grown carbon fiber is employed. That is, in the case where branched vapor grown carbon fiber is added to the

abrasive composite material in the same amount as typical vapor grown carbon fiber, the resultant composite material exhibits further enhanced electrical conductivity, thermal conductivity, tribological characteristics, and elasticity.

[0027]

In the carbon fiber employed in the present invention, preferably, boron is contained in crystals constituting the carbon fiber in an amount of 0.01 to 5 mass%.

When the carbon fiber contains boron, the crystal layered structure is developed, and thus electrical conductivity is enhanced. In addition, by virtue of enhancement of crystallinity and the effect of boron contained in crystal planes, corrosion resistance of the carbon fiber is improved, and surface charge distribution varies. Therefore, the carbon fiber exhibits improved wettability to the matrix and improved tribological characteristics. When the boron-containing vapor grown carbon fiber is added to the abrasive composite material, friction resistance during the course of polishing can be reduced, and generation of friction heat can be suppressed. Furthermore, since adhesion of the carbon fiber to the matrix is improved, falling of the carbon fiber during the course of polishing can be suppressed.

[0028]

The abrasive composite material of the present invention contains a matrix (e.g., substrate or fabric), abrasive grains, and carbon fiber, wherein the abrasive

grains and carbon powder are fixed onto the matrix. The abrasive composite material can be formed into, for example, a grinding wheel through molding of a mixture of the matrix, which also serves as a binder, the abrasive grains, and the carbon fiber; a polishing blade by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of a metallic or ceramic substrate serving as the matrix; or a polishing pad by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of the matrix formed of non-woven fabric.

[0029]

When the abrasive composite material is formed into a grinding wheel, the carbon fiber added to the composite material is preferably 5 to 40 vol.%, more preferably 10 to 30 vol.%. When the amount of the carbon fiber is 5 vol.% or less, the carbon fiber fails to impart sufficient tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance to the abrasive composite material, and therefore, the composite material fails to provide a planar polished surface. In contrast, when the amount of the carbon fiber is 40 vol.% or more, adhesion between the carbon fiber and the matrix is impaired, and the mechanical strength of the abrasive composite material is lowered. As a result, the carbon fiber or abrasive grains fall from the abrasive composite material during the course of polishing, leading to lowering of the quality of the composite material and a workpiece.

[0030]

When the abrasive composite material is formed into a product by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of a substrate, or a product by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of the matrix formed of, for example, non-woven fabric, the amount of the carbon fiber is preferably regulated such that the ratio by volume of the abrasive grains to the carbon fiber is 1:0.5 to 1:1.

[0031]

The above-prepared abrasive composite material of the present invention, which contains the carbon fiber, exhibits elasticity, and thus does not apply excess load to an object to be polished. Therefore, the composite material enables suppression of generation of polishing marks.

Planarization of a workpiece requires planarity of a grinding wheel and uniform distribution of pressure at the surface at which the grinding wheel is in contact with the workpiece. When carbon fiber having low bulk density and exhibiting high elasticity, in particular, vapor grown carbon fiber, is added to the grinding wheel, the elastic modulus of the grinding wheel is increased, uniform polishing pressure can be applied to a workpiece, and the surface of the workpiece can be uniformly planarized. Even when excess pressure is applied to the workpiece, by virtue of pressure reduction by deformation of the grinding wheel, the depth of polishing marks can be decreased, and the number of polishing

marks can be reduced.

In addition, since the grinding wheel exhibits enhanced tribological characteristics, electrical conductivity, thermal conductivity, and corrosion resistance, effects caused by physical or chemical factors during the course of polishing can be reduced.

Particularly when a semiconductor is ground or polished by use of diamond abrasive grains, oxidation of the diamond abrasive grains caused by oxygen in air and friction heat can be suppressed, and the lifetime of the abrasive composite material can be lengthened.

Furthermore, during the course of polishing of a semiconductor wafer or during the course of dressing of a polishing pad, falling of the abrasive grains of the abrasive composite material can be suppressed.

When the abrasive composite material is employed for polishing of a semiconductor wafer, friction resistance between the semiconductor wafer and a portion of the composite material other than the abrasive grains can be reduced, non-uniform polishing of the semiconductor wafer (i.e., workpiece) can be prevented, the surface of the wafer can be highly planarized, and polishing burn can be suppressed through radiation of generated friction heat.

[0032]

In addition, when the abrasive composite material is formed into a grinding wheel, the composite material can impart excellent mold releasability to the grinding wheel.

When a workpiece is polished by the grinding wheel, which comes into surface contact with the workpiece, planarity of the polishing surface of the grinding wheel affects planarity of the thus-polished workpiece. Therefore, when a grinding wheel is formed from the abrasive composite material, a critical point is to remove the thus-formed grinding wheel from a mold so as to strictly conform the shape of 'the mold. In order to improve mold releasability during forming of the grinding wheel, a mold release agent, etc. may be employed. However, when the carbon-fiber-containing abrasive composite material of the present invention is employed, the resultant grinding wheel exhibits tribological characteristics, and thus exhibits excellent mold releasability. Therefore, when the grinding wheel is employed for grinding or polishing of a workpiece, friction resistance between the workpiece and a portion of the grinding wheel other than the abrasive grains can be reduced during the course of grinding or polishing.

[0033]

In addition, the abrasive composite material can impart electrical conductivity to the grinding wheel. Therefore, the thickness of the grinding wheel after polishing can be electrically measured, which enables control operations, including exchange of the grinding wheel.

In the case of production of a product through continuous polishing, in general, the product is planarized while the polishing amount is controlled by the polishing

time, and therefore, measuring the thickness of a grinding wheel which has been employed for polishing is important, but the thickness of the grinding wheel is difficult to measure by means of laser or light. However, in the case of the carbon-fiber-containing grinding wheel of the present invention, since the carbon fiber exhibits high electrical conductivity, electrical conductivity is imparted to the abrasive grains and the grinding wheel, and the thickness of the grinding wheel can be controlled by means of electrical resistance. When the grinding wheel is provided on a substrate exhibiting electrical conductivity, electrical conduction is established throughout the resultant product, and thus the position of the substrate can be detected through electrical conduction detection means. In addition, when the position of the substrate is controlled through control means, the same polishing conditions can be reproduced at any time.

[0034]

In order to suppress polishing burn or exhaustion of the abrasive grains caused by friction heat generated during the course of polishing, in general, a coolant such as water is supplied to the grinding wheel during polishing. However, when the carbon fiber is added to the grinding wheel, further enhanced heat radiation and cooling effects can be obtained, and thus exhaustion of the abrasive grains can be suppressed.

[0035]

Having been described grinding or polishing of a

workpiece by use of the abrasive composite material of the present invention, the composite material can be employed in a dresser for a polishing pad.

When a semiconductor wafer is polished by use of, for example, a slurry containing dispersed abrasive grains, a polishing pad is cleaned between a wafer polishing step and the subsequent wafer polishing step. When a semiconductor wafer is subjected to, for example, chemical mechanical polishing, in many cases, a polishing pad formed of polyurethane foam is employed. When the polishing pad is observed under an electron microscope after polishing of the wafer, abrasive grains or chips of the workpiece are found to be deposited into pores on the pad surface, or the pores are found to be clogged by, for example, the effect of an additive (etchant) contained in the slurry. The clogged pores cause a decrease in the polishing speed, and the deposited abrasive grains cause an increase in the number of polishing marks. Therefore, after polishing of the wafer, the polishing pad must be subjected to dressing, thereby removing excess abrasive grains, and returning the clogged pores to their original state. Since the pad surface often exhibits acidity or alkalinity due to the presence of the etchant contained in the slurry, preferably, the surface of a dresser to be employed exhibits chemical stability. When carbon fiber is added to the dresser, the area of a portion of the dresser that comes into contact with an acid or an alkali can be reduced, thereby attaining chemical stability,

and falling of abrasive grains can be suppressed.

[0036]

Next will be described the method for processing (grinding or polishing) an electronic part by use of grinding wheel, a grinding material, or a polishing material, which contains the abrasive composite material of the present invention.

A semiconductor integrated circuit will now be described as an example of an electronic part. In production of a semiconductor integrated circuit, an insulating layer is formed on the surface of a silicon wafer which has undergone mirror polishing, and a circuit pattern formed of a thin film of a metal (e.g., aluminum) is formed on the insulating layer. In recent years, in order to enhance performance of an integrated circuit, a multi-layer integrated circuit including a plurality of insulating layers and circuit patterns has been widely employed. In formation of a fine circuit pattern, a circuit pattern is printed, through exposure, onto a photo-resist film formed on the surface of a conductive thin film, followed by etching. Therefore, when the surface onto which a circuit pattern is to be printed does not have planarity, a precise circuit pattern cannot be formed. In the case of production of such a multi-layer semiconductor integrated circuit, a silicon wafer must be subjected to mirror polishing, and an interlayer insulating film or a metallic thin film for formation of a circuit pattern must be subjected to high-precision polishing,

thereby imparting planarity thereto.

[0037]

The electronic part processing method of the present invention is applied to grinding (including cutting) or polishing of a semiconductor material such as a silicon wafer, or to polishing of an interlayer insulating film or a metallic thin film to be formed into a circuit pattern. In the electronic part processing method, when a grinding wheel, grinding material, or polishing material formed of the abrasive composite material of the present invention is employed, occurrence of non-uniform polishing such as dishing or thinning can be prevented, and there can be obtained a precisely processed surface having neither micro-scratches nor polishing marks and exhibiting high planarity.

Particularly, the grinding wheel of the present invention is useful for grinding or polishing of silicon, such as polycrystalline silicon, single-crystal silicon, or amorphous silicon.

[0038]

[Examples]

The present invention will next be described in more detail by way of Examples, which should not be construed as limiting the invention thereto. In the below-described Examples, characteristics are measured by means of the following methods.

(1) BET specific surface area

BET specific surface area was calculated from a

nitrogen adsorption isothermal curve at the liquid nitrogen temperature by use of NOVA 1200 (product of Quantachrome) by means of the BET method and the BJH method. The adsorption amount of nitrogen was measured at a relative pressure (P/P_0) of 0.01 to 1.0.

(2) Raman scattering spectrum

Raman scattering spectrum of carbon fiber was obtained under the following conditions: excitation light: argon (Ar) laser (wavelength: 514.5 nm), detector: CCD (charge coupled device), slit distance: 500 μm, exposure time: 60 seconds.

[0039]

(Example 1)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 200 nm, aspect ratio: 100, BET specific surface area: 10 m^2/g, d_{002}: 0.339 nm, Id/Ig: 0.1) (30 vol.%). The resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel were rotated in the same direction such that the relative

velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed and the surface roughness were found to be sufficiently practical levels; i.e., 300 nm/min and 2.0 nm, respectively. Observation of the polished surface under an optical microscope revealed that no polishing mark was generated on the wafer surface.

[0040]

(Example 2)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 20 nm, aspect ratio: 100, BET specific surface area: 100 m^2/g, d_{002}: 0.341 nm, Id/Ig: 0.2) (30 vol.%). The resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel

were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed and the surface roughness were found to be sufficiently practical levels; i.e., 280 nm/min and 1.5 nm, respectively. Observation of the polished surface under an optical microscope revealed that no polishing mark was generated on the wafer surface.

[0041]

(Comparative Example 1)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and the resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the

thicknesses of the wafer before and after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed was found to be a sufficient level; i.e., 400 nm/min, but the surface roughness was found to increase to 10.0 nm. Observation of the polished surface under an optical microscope revealed that polishing marks were generated on the wafer surface in an amount of about 13 marks/cm^2.

[0042]

(Comparative Example 2)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 20 nm, aspect ratio: 2, BET specific surface area: 130 m^2/g, d_{002}: 0.341 nm, Id/Ig: 0.2) (30 vol.%). The resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel

were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed was found to be a sufficient level; i.e., 370 nm/min, but the surface roughness was found to increase to 8.5 nm. Observation of the polished surface under an optical microscope revealed that polishing marks were generated on the wafer surface in an amount of about 10 marks/cm^2.

Table 1 shows the results of polishing performed in the Examples and Comparative Examples.

[0043]

Table 1 shows the percent defective and tribological characteristics of the grinding wheels of Examples 1 and 2 and Comparative Example 1, the percent defective being evaluated when the grinding wheel was released from the mold.

As used herein, "the percent defective" is defined by the percentage of grinding wheels which were broken when released from the mold, or grinding wheels whose surface was partially exfoliated and deposited onto the mold.

Tribological characteristics of the grinding wheel were evaluated by means of the thrust-type friction test. Specifically, an insulating-film-coated silicon wafer was

pressed onto the grinding wheel for 60 minutes under application of a load of 147 kP, while the grinding wheel was rotated at 20 cm/sec. The amount of wear of the grinding wheel was measured after the test, and the thus-measured value was employed as an indicator for evaluation of tribological characteristics.

[0044]

[Table 1]

	Ex. 1	Ex. 2	Comp. Ex. 1	Comp. Ex. 2
Polishing speed (nm/min)	300	280	400	370
Surface roughness (nm)	2.0	1.5	0.0	8.5
Polishing marks (marks/cm^2)	0	0	13	10
Percent defective (%)	1	1	40	-
Wear amount of grinding wheel (mg)	30	25	560	-

[0045]

As is clear from Table 1, in the case of the grinding wheel of the present invention, a sufficiently practical polishing speed is attained, surface roughness is small, and high-precision polishing is attained without generating polishing marks.

In contrast, in the case of Comparative Example 1, in which carbon fiber is not employed, polishing speed is high, but surface roughness is significant, and polishing marks are generated. Meanwhile, in the case of Comparative Example 2, in which carbon fiber having a small diameter and a low aspect ratio is employed, surface roughness is significant, and polishing marks are generated.

As is clear from Table 1, when carbon fiber is added to

the grinding wheel, mold releasability of the grinding wheel is improved. The results of the friction test reveal that addition of carbon fiber to the grinding wheel improves tribological characteristics thereof, and exhibits the effect of reducing the amount of wear of the grinding wheel.

[0046]

[Effects of the Invention]

Since the abrasive composite material of the present invention contains carbon fiber, when the composite material is employed in a grinding material or a polishing material, the resultant material exhibits tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance, reducing adverse effects attributed to physical or chemical factors during the course of processing. Therefore, friction resistance is reduced, non-uniform polishing is prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be attained without generating scratches or polishing marks. In addition, falling of abrasive grains during the course of grinding or polishing can be suppressed, generation of polishing marks can be suppressed, burden on post-treatment of abrasive grains can be reduced, and a grinding material or polishing material having long lifetime can be provided.

[0047]

Furthermore, when the abrasive composite material of the present invention is formed into a grinding wheel, the composite material can impart excellent mold releasability to

the grinding wheel.

In addition, when the abrasive composite material is formed into a grinding wheel, electrical conductivity is imparted to the grinding wheel. Therefore, the thickness of the grinding wheel after polishing can be electrically measured, which enables control operations, including exchange of the grinding wheel.

Moreover, enhanced heat radiation and cooling effects can be obtained, and thus exhaustion of abrasive grains can be suppressed.

[0048]

When the electronic part processing method of the present invention is employed, a semiconductor substrate, or an interlayer insulating film or circuit pattern constituting an electronic device can be processed at high precision and high efficiency. Particularly, the processing method exhibits its effects when employed for grinding or polishing of silicon, such as polycrystalline silicon, single-crystal silicon, or amorphous silicon.

The abrasive composite material of the present invention can be employed in a dresser for a polishing pad.